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# GEOLOGY AND GEOCHEMISTRY OF THE SINUK RIVER BARITE DEPOSIT, SEWARD PENINSULA, ALASKA

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By D. A. BROBST, D. M. PINCKNEY, and C. L. SAINSBURY

## Abstract

Barite, fluorite, galena, sphalerite, boulangerite, and associated silver and gold were introduced into thrust sheets of marble and schist of the Nome Group (Precambrian age) in the Sinuk River barite deposit along the Teller Highway about 20 miles north of Nome on the Seward Peninsula, Alaska. Most of the introduced minerals were emplaced pervasively, followed by some later shearing and recrystallization which occurred at a temperature of about 250°C, as indicated by study of fluid inclusions in the fluorite. Fissure fillings consisting principally of calcite and aragonite and some unsheared galena and boulangerite and associated gold and silver possibly indicate a second epoch of mineralization in the area. The vertical and lateral extent of the mineralization is unknown, although gossans with base metals are known in the surrounding region. Mineralization might have taken place in shear zones between thrust sheets or might have penetrated favorable host rocks in either the overriding or underlying sheet or both. Further exploration seems warranted.

## Introduction and history

Barite, fluorite, goethite, galena, sphalerite, boulangerite, and associated silver and gold occur in marble and schist in the Sinuk River barite deposit that lie adjacent to the Teller Highway about 20 miles north of Nome, on the Seward Peninsula, Alaska (fig. 1). The deposit, also known as the quarry prospect (Herreid, 1966, p. 3), lies on the divide between the Cripple River and Washington Creek, a tributary of the Sinuk River, in the NW 1/4 sec. 19 (and adjacent sections), T. 9 S., R. 35 W., in the Nome C-2 quadrangle. New observations on the stratigraphic, structural, and mineralogical features of the barite deposit suggest that a large area is worthy of exploration for mineral deposits of commercial value.

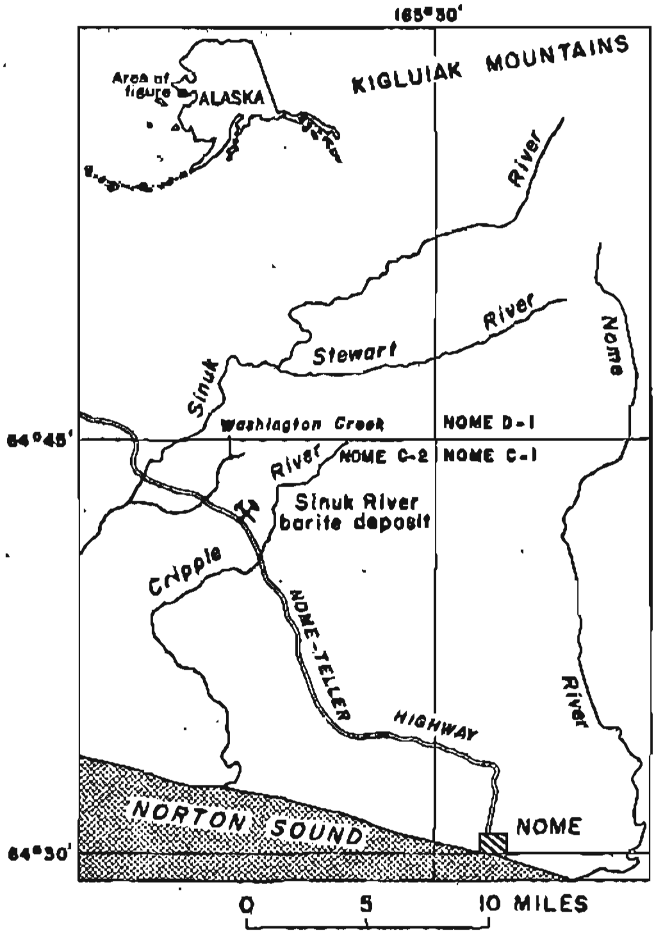

Figure 1.--Index map of the Nome area, Seward Peninsula, showing the location of the Sinuk River barite deposit.

In earlier times, the interest of prospectors and geologists has been drawn to the Sinuk River area by gossans. Eakin (1915) first described the gossans and after spending only a day in the area had the general impression (p. 362), "that there had been strong mineralization at certain localities, and that the mineralizing agencies had affected a considerable area." The gossans were examined by A. B. Shallit (unpub. data) in 1942 for the Alaska Territorial Department of Mines and again by Mulligan (1965) and rejected as sources of iron ore. Some geologic and geochemical work was done in the area by Herreid (1966, p. 3, figs. 1, 3), who reported a strong geochemical anomaly for lead and zinc in the soil of an area 2,000 by 6,000 feet. This area includes a large borrow pit from which road metal was taken for construction of the Teller Highway. The pit became known as the quarry prospect. Recently Mr. Charles Volkheimer and associates, of Nome, found barite in the pit and staked the quarry site and environs as the Sinuk River barite claims.

In August 1970, Brobst spent 2 days examining and sampling the Sinuk River barite deposit after an introduction to the geology of the area by Sainsbury, who has supplied much information on the local stratigraphy and geology of the Seward Peninsula. Studies of the fluid inclusions were contributed by Pinckney. Additional studies of the samples included petrographic examination of thin and polished sections, mineral identifications by X-ray diffraction, spectrographic analyses of rocks and minerals, and fire assays for precious metals. The authors acknowledge the assistance of L. A. Bradley for the spectrographic analyses, J. B. McHugh for the instrumental determinations of mercury, W. D. Goss, A. W. Haubert, J. A. Thomas, and L. B. Riley for the fire assays, J. D. Tucker for the X-ray diffractograms, and Irving Friedman and K. G. Hardcastle for the determination of the carbon dioxide-to-water ratio in the fluid inclusions. The authors also thank Mr. Charles Volkheimer and associates for permission to publish the results of this study.

## Barite-fluorite deposit

The deposit is exposed in a stripped area about 225 by 1,000 feet, the long dimension of which trends about N. 10° W. up a gently sloping hill. The cut exposes a sequence of folded, interlayered marble and chloritic schist in three benches referred to as the upper, middle, and lower benches. The upper bench is composed mostly of marble, but contains some schist. A shaft and short unroofed crosscut lie in the northwest corner of the middle bench. This bench is composed mostly of schist and some marble. The lower bench occupies the southern third of the cut and also is composed mostly of schist. A geologic map of the cut as it appeared in 1965 was included in a report by Herreid (1966, fig. 3), but that map showed only parts of what are now the upper and middle benches.

A detailed stratigraphic sequence of marble and schist was not worked out, but marble seems to be more abundant in the upper than in the lower part of the sequence in the cut. The rocks are assigned by Sainsbury to the Nome Group, which comprises a thick sequence of interbedded schistose marble and epidote-chlorite-albite-actinolite schists of Precambrian age. Similar rocks crop out over large areas of the Seward Peninsula; they are well described by Moffit (1913), Smith (1910), and Sainsbury, Coleman, and Kachadoorian (1970).

The marble and schist have been deformed, thermally altered, and pervasively mineralized to various degrees. The compositional layers and foliation have various attitudes in the exposures, but a general southeasterly dip prevails at the cut. A well-developed lineation trends slightly east of south and generally plunges 15° to 30° SE. Steeply dipping veins only a few inches wide, consisting mostly of colloform calcite and aragonite, trend west and transect the earlier structural features. The ore deposits occur principally along the foliation planes of the host rocks, but some veins and veinlets crosscut both the marble and the schist.

At several places in the cut, the marble was replaced by masses of pale-yellowish-orange dolomite. A sample of this rock consists of cloudy grains of dolomite about 0.01 mm across. The rock is cut by thin veinlets of calcite and sulfide. The sulfide minerals apparently account for the lead, zinc, antimony, and silver shown in the spectrographic analysis (table 1, sample 17).

Some of the dolomite has been brecciated to angular fragments 3 mm to 3 cm across and cemented by fine-grained white quartz that is free of inclusions. Some sericite lies in the interstices of both the quartz and the carbonate. X-ray diffraction analysis indicated that some calcite and fluorite also occur in the breccia. The brecciated dolomite also contains some sulfides which probably account for the lead, zinc, and silver shown in the spectrographic analysis (table 1, sample 22).

Table 1.—*Spectrographic analyses of samples from the Sinuk River barite deposit, Seward Peninsula, Alaska*

Six-step semiquantitative spectrographic analyses by L. A. Bradley. Mercury determinations by J. B. McHugh by instrumental methods. G, amount greater than 10 percent; L, detected, but below limit of detection; N, not detected at limit of detection; ppm, parts per million (conversion 10,000 ppm = 1 percent).

Asterisk (*) indicates sample in which additional elements were found (in ppm):

| | |
|---|---|
| Sample 20: 50 B, 15 Co, 30 La, 15 Sc, 20 Ga. | Sample 15: L B, 30 Cd. |
| Sample 21: 70 B, 15 Co, 70 La, 30 Sc, 150 Ce,<br>50 Ga, 100 Nd. | Sample 14: 30 Cd, 3 Mo.<br>Sample 14A: 20 Co, 70 La, 15 Sc, 150 Ce. |
| Sample 4: 70 La. | Sample 14B: 2000 As, 7 Mo, 30 Sn. |

| Material— | Marble | Marble | Sericite schist | Chlorite schist | Barite | Barite | Barite | Breccia | Calcite | Aragonite | Fluorite | Fluorite |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No— | 7 | 18 | *20 | *21 | 3 | 25 | 8 | 22 | 13 | 24 | *4 | 5 |
| | | | | | | Analyses in percent | | | | | | |
| Si— | 1.5 | 0.5 | G | G | 0.05 | 0.2 | 1.5 | 2.0 | L | 0.007 | 0.05 | 0.02 |
| Al— | .15 | .2 | 7.0 | G | .002 | .02 | .005 | .03 | L | .02 | .1 | .1 |
| Fe— | .07 | .07 | 5.0 | 7.0 | .007 | .05 | .1 | 3.0 | 0.002 | .1 | .03 | .007 |
| Mg— | .7 | .2 | .2 | .7 | L | .007 | .005 | 7.0 | .7 | .02 | .002 | L |
| Ca— | G | G | 5.0 | .7 | .2 | .7 | 2.0 | G | G | G | G | G |
| Ti— | .003 | .005 | .5 | .1 | N | L | N | L | L | N | .0005 | L |
| | | | | | | Analyses in parts per million | | | | | | |
| Mn— | 100 | 30 | 500 | 300 | 30 | 7 | 50 | 700 | 5 | 5 | 50 | 30 |
| Ag— | N | N | N | N | N | N | N | 3 | N | 1.5 | N | N |
| Ba— | 150 | 30 | 700 | 3000 | G | G | G | 30 | 70 | 150 | 700 | 200 |
| Be— | N | N | 2 | 5 | N | 1.5 | N | N | N | N | 1.5 | N |
| Cr— | 7 | 2 | 70 | 150 | L | 1 | L | 3 | L | 1 | N | N |
| Cu— | 1 | 1 | L | 1.5 | L | 1.5 | 5 | 70 | 15 | 50 | 1.5 | L |
| Nb— | N | N | L | 10 | N | N | N | N | N | N | N | N |
| Ni— | L | N | 30 | 70 | N | N | L | 10 | 10 | N | N | N |
| Pb— | 10 | 150 | 100 | 150 | 70 | 70 | 100 | 3000 | 200 | N | 50 | L |
| Sb— | N | N | 300 | 300 | N | N | N | N | N | 100 | N | N |
| Sr— | 1500 | 2000 | 100 | 70 | 7000 | 15,000 | 10,000 | 100 | 300 | N | 150 | 30 |
| V— | N | N | 100 | 300 | N | N | N | L | N | 7000 | N | N |
| Y— | N | N | 30 | 70 | L | N | N | N | N | N | 70 | 150 |
| Yb— | N | N | 5 | N | N | N | N | N | N | N | 3 | 3 |
| Zn— | N | N | N | 200 | N | N | N | 2000 | 5000 | 1500 | N | N |
| Zr— | N | 20 | 200 | 500 | N | N | N | N | N | N | N | N |
| Hg— | .01 | .03 | .03 | .04 | .04 | .44 | .13 | .25 | .02 | .03 | .05 | .02 |

Table 1.--*Spectrographic analyses of samples from the Sinuk River barite deposit, Seward Peninsula, Alaska*--*Continued*

| Material-- | Fluorite | Fluorite | Fluorite | Fluorite | Fluorite | Quartz sulfides | Dolomite sulfides | Gossan | Calcite | Composite | Sheared rock | Vein |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No-- | 6 | 9 | 10 | 11 | 19 | *15 | 17 | 23 | 1 | *14 | *14A | *14B |
| | | | | | | Analyses in percent | | | | | | |
| Si---------- | 0.02 | 0.07 | 0.05 | 0.02 | 0.01 | G | 1.0 | 0.5 | 0.07 | 0.7 | 3.0 | G |
| Al---------- | .1 | .1 | .15 | .07 | .15 | 0.02 | .01 | .3 | .05 | .07 | .2 | 0.02 |
| Fe---------- | .01 | .01 | .005 | .002 | .005 | .2 | .1 | G | .02 | .7 | G | .07 |
| Mg---------- | L | L | L | L | .005 | .05 | 7.0 | .2 | .02 | 10.0 | .005 | .02 |
| Ca---------- | G | G | G | G | G | .15 | 7.0 | 7.0 | G | G | G | .7 |
| Ti---------- | L | L | L | N | N | .0002 | N | L | .001 | .0002 | L | L |
| | | | | | | Analyses in parts per million | | | | | | |
| Mn---------- | 20 | 20 | 30 | 15 | 30 | 20 | 200 | 70 | 30 | 200 | 2000 | 7 |
| Ag---------- | N | N | 2 | N | N | 200 | 1.5 | N | N | 30 | N | 500 |
| Ba---------- | 100 | 500 | 150 | 70 | 20 | 70 | 7 | 70 | 30 | 100 | 70 | 2000 |
| Be---------- | 1.5 | N | N | N | N | N | N | N | N | N | 3 | N |
| Cr---------- | N | N | N | N | N | L | 7 | 7 | L | 3 | 1.5 | 5 |
| Cu---------- | L | L | 1 | N | L | 100 | 10 | 30 | 1.5 | 150 | 500 | 700 |
| Nb---------- | N | N | N | N | N | L | L | L | N | L | L | L |
| Ni---------- | N | L | N | N | N | N | 5 | 30 | L | 7 | 15 | L |
| Pb---------- | 10 | 20 | 100 | N | 150 | G | 1000 | 700 | 15 | G | 5000 | G |
| Sb---------- | N | N | N | N | N | 1500 | 150 | 150 | N | 50,000 | N | G |
| Sr---------- | 30 | 50 | 20 | 70 | 20 | 10 | 50 | 30 | 2000 | 100 | 150 | 100 |
| V----------- | N | N | N | N | N | N | N | N | N | 10 | 30 | L |
| Y----------- | 300 | 70 | 30 | 150 | 70 | N | N | N | N | L | 100 | 15 |
| Yb---------- | 3 | N | N | 1.5 | 1 | N | N | N | N | N | N | N |
| Zn---------- | N | N | N | N | N | 300 | 2000 | 2000 | N | 3000 | 5000 | 3000 |
| Zr---------- | N | N | N | N | N | N | N | N | N | N | N | N |
| Hg---------- | .02 | .02 | .13 | .05 | .02 | 3.0 | .19 | .86 | .06 | 3.30 | .63 | .58 |

*Sample description and locality*

7. Calcite marble, upper bench.

18. Calcite marble, west side of lower bench.

20. Quartz-sericite schist, west side of middle bench.

21. Quartz-chlorite-sericite schist, west side of middle bench.

3. White barite, bulldozer cut northwest of main cut.

25. White barite, north end of upper bench.

8. White barite, folded into marble, upper bench.

22. Dolomite-calcite-quartz breccia, upper bench.

13. White colloform calcite, east-trending vein, south end of upper bench.

24. Pale-yellowish-green aragonite, east-trending vein, upper bench.

4. Purple fluorite, lower bench.

5. Light-purple fluorite, lower bench. Fluid inclusions studied in detail.

6. White fluorite, upper bench.

9. White fluorite, east side of upper bench.

10. White fluorite, collected about 6 feet north of sample 9.

11. Clear fluorite, upper bench.

19. Deep-purple fluorite clots in iron-stained schist near west side of north end of upper bench.

15. Quartz-sulfide mass, east side of middle bench.

17. Dolomite with sulfide veinlets, east side of middle bench.

23. Gossan (goethite-calcite rock), upper bench.

1. White calcite, vein on lower bench.

14. Composite of sheared fluorite rock and unsheared vein, east side of middle bench.

14A. Sheared rock with fluorite, calcite, quartz, and goethite at edge of vein; locality same as for 14.

14B. Sulfide minerals and quartz from center of vein; locality same as for 14.

## Country rocks

The unmineralized marble exposed at the deposit is gray to bluish white and is composed of more than 95 percent calcite, commonly twinned, with a grain size of 0.1 to 1 mm. The marble is schistose, its foliation accentuated by thin layers of shiny flakes of sericite interstitial to the calcite. Round to subangular grains of quartz 0.02 to 0.2 mm in diameter are scattered through the rock. Spectrographic analyses of two fresh samples of this marble from the upper and lower benches are shown in table 1 (samples 7 and 18). These analyses indicate the low initial content of barium.

Some of the marble has been altered by bleaching and dolomitization. Bleaching produced streaks and patches of white marble within the unaltered gray marble. Some of the bleached rock is stained by iron oxides.

The least altered schists are silvery to dark greenish gray and consist of various proportions of quartz, muscovite (including sericite), and chlorite associated with smaller amounts of albite, epidote, hornblende, garnet, magnetite-ilmenite, and sulfide minerals. The streaks of micaceous minerals are bent and broken and separated by streaks of quartz in grains 0.1 to 0.2 mm across. Some muscovite and chlorite are included in the quartz, some sericite occurs interstitially to the quartz, and some grains and patches of calcite are associated with quartz. Some schist contains small grains of high-calcium garnet (andradite) which is pale red and greatly fractured. Elongate streaks of opaque ilmenite-magnetite and sulfide minerals occur with the muscovite. Spectrographic analyses of two samples of this type of schist from the west side of the middle bench are shown in table 1 (samples 20 and 21). The suite and amount of the trace elements, especially the zinc and antimony, certainly suggest that even the freshest appearing schist has been hydrothermally altered.

Because the schist has been altered pervasively, the marble also probably was altered similarly. If so, the streaks and patches of either bleached or dolomitized rock mentioned above indicate places where the marble was more intensely altered.

## Introduced minerals

The introduced minerals occur chiefly as streaks and pods in the pervasively altered schist and marble and to a much lesser extent as thin veins which trend west across the exposures. The streaks and pods are a few inches to several feet thick and as much as several tens of feet long. They contain various amounts and combinations of barite, fluorite, sulfides of lead, zinc, antimony, and iron, and precious metals, along with their weathering products and a gangue of calcite, dolomite, and quartz. The streaks and pods generally follow the foliation of the host rocks and the contacts of the various layers of marble and schist.

White barite occurs mostly in marble on the upper bench and is especially abundant in a bulldozer cut adjacent to the northwest side of the main cut. The barite (sample 3) from the bulldozer cut is sugary-grained and has a lineation induced by shear. In thin section the grains of barite are 0.5 to 1.5 mm across, and many are twinned. The only accessory minerals observed are scattered round grains of quartz and pyrite, the latter surrounded by thin rims of iron oxide. A similar-looking specimen of barite (sample 25) from the north end of the upper bench contains a little calcite. The texture of both samples is sutured, and relict grain boundaries are indicative of at least a partial recrystallization of the barite. Spectrographic analyses of barite samples 3 and 25 (table 1) indicate a good-quality barite. The strontium values are not especially unusual, because barium and strontium freely substitute to several percent in their respective sulfates.

Barite also occurs with other minerals in some of the pods; for example, with fluorite and quartz in the crest of a small fold in marble on the upper bench. In a sample from this locality, grains of barite and fluorite, 0.1 to 0.2 mm across, are scattered in finer grained quartz. Some small amounts of sericite lie in the interstices of the aforementioned minerals. Some round grains of pyrite only 0.04 mm in diameter are scattered through the sample. The spectrographic analysis (table 1, sample 8) suggests that most of the material analyzed is barite.

The fluorite occurs in clots and streaks from several inches to several feet across. Most of the fluorite is white or light green and purple, but some is colorless. Most of the fluorite examined under the microscope has been sheared and at least partly recrystallized; relict traces of former grain boundaries are easily visible. Some fractures as wide as 0.1 mm are filled by quartz or calcite. In some thin sections, hair fractures and cleavage planes are "corroded" by calcite, and the fluorite apparently has been thoroughly penetrated by later solutions. The fluorite regarded as typical of this deposit is nearly pure. Spectrographic analyses of seven samples of fluorite shown in table 1 (samples 4, 5, 6, 9, 10, 11, and 19) indicate very little barium or other elements.

The sulfides galena (PbS), sphalerite (ZnS), and boulangerite ($Pb_5Sb_4S_{11}$) have been identified in polished sections and by X-ray diffraction. They occur as scattered grains or aggregates in the clots and streaks with other introduced minerals and as finely disseminated grains in the calcite and aragonite of the late west-trending veins.

Some of the sulfide minerals are sheared and some are not. Textural relations suggest that at least some of the sulfide minerals were introduced later than the fluorite and barite.

A body of quartz-rich rock on the east side of the middle bench has discontinuous thin streaks of sheared galena. The quartz matrix has been partly recrystallized, and some of the relict boundaries have been preserved. A spectrographic analysis of this rock (table 1, sample 15) also indicates the presence of anomalous silver and antimony.

Sheared yellow-orange fluorite-calcite-quartz rock with goethite at a marble-schist contact on the east side of the middle bench contains streaks or veins of unsheared quartz, galena, and boulangerite; this veining suggests that the latter minerals perhaps are younger than the enclosing sheared rock. Spectrographic analyses of this material are shown in table 1. Sample 14A is the sheared fluorite-rich rock. Sample 14B, the unsheared quartz-sulfide vein, contains 2,000 ppm arsenic, but no specific arsenic minerals were identified. Sample 14 is a composite of the sheared and unsheared material. The traces of tin, molybdenum, and rare earths found in these samples are similar to those known in many altered rocks on the Seward Peninsula.

Herreid (1966) reported some silver and gold in the rocks of this area. The amounts of silver listed in some of the analyses in table 1 of this report warranted further investigation. Fire assay data for eight samples selected from those collected at the claims are shown in table 2. The sample numbers and material correspond to those in table 1. No specific gold or silver minerals were identified in this study.

Trace amounts of mercury were detected in all of the samples from the barite deposit (table 1). Background values for the mercury content of rocks on the Seward Peninsula are less than 0.09 ppm. Thus, 10 of the samples, mostly those with abundant sulfide minerals, contain anomalous amounts of mercury. The samples of schist and marble in the mineralized area do not contain anomalous amounts of mercury. The anomalous amounts of mercury seem to accompany the lead and zinc minerals and barite, so geochemical prospecting with tests for Pb-Zn or even Ba could be successful and require less cost as well as less complicated techniques than prospecting with mercury.

Colloform calcite and aragonite with disseminated fine-grained galena and sphalerite constitute the principal filling of a group of west-trending veins that attain a maximum thickness of several inches. The veins were fractured and healed during the deposition of the carbonate minerals. Spectrographic analyses of samples from two of these veins are listed in table 1 (samples 13 and 24).

Table 2.--*Fire assay values of selected samples from the Sinuk River barite deposit, Seward Peninsula, Alaska*

[Gold determined by fire assay plus atomic absorption method by W. D. Goss, A. W. Haubert, and J. A. Thomas. Silver determined by fire assay difference method by L. B. Riley]

| Sample No. | Material | Gold (ppm) | Gold (oz/ton) | Silver (ppm) | Silver (oz/ton) |
|---|---|---|---|---|---|
| 8 | White barite---------- | <0.05 | ---- | --- | ---- |
| 10 | Fluorite------------- | <.05 | ---- | --- | ---- |
| 14 | Composite of sheared rock and unsheared vein--------------- | .2 | <0.1 | 260 | 7.65 |
| 15 | Quartz-sulfide mass-- | 3.6 | .1 | 155 | 4.55 |
| 17 | Dolomite------------- | <.05 | ---- | --- | ---- |
| 22 | Dolomite breccia----- | <.05 | ---- | --- | ---- |
| 23 | Gossan--------------- | <.05 | ---- | --- | ---- |
| 25 | White barite--------- | .8 | <.1 | --- | ---- |

## Gossan

A small gossan is exposed on the upper bench. The material looks dense, but it contains a few percent, by volume, of tiny cavities which are lined with calcite. Thin-section and X-ray studies show that the material is chiefly goethite, which is both very fine grained and well crystallized. A sample of this material contains 2,000 ppm zinc and a little lead and copper (table 1, sample 23). The lead and zinc content in the gossan material is roughly comparable to that in the analysis of the sulfide materials shown in table 1.

Pyrite ($FeS_2$) is a common accessory mineral disseminated through many rocks at the deposit and some also is associated with galena. There is no evidence, however, to suggest either that large amounts of pyrite were introduced to the area or that the goethite-rich gossan was derived from pyrite.

## Fluid inclusions

Fluid inclusions are abundant in all of the fluorite that was studied. Slices of fluorite about 2 mm thick were cut and polished on both sides. These slices were examined under a microscope equipped with a heating stage and a device to record temperatures.

The inclusions are of two kinds, those along healed fracture planes and those along the grain boundaries of recrystallized fluorite. The inclusions along the healed fracture planes are mostly equidimensional and have negative crystal faces, as though they may be primary inclusions; that is, fluid trapped along crystal faces while the fluorite was being deposited. The planes defined by these inclusions, however, seem to be curved and do not meet at right angles. Thus, they are fracture planes in massive fluorite and not crystallographic planes, and these inclusions are of secondary origin.

Fluid inclusions of the second type--those along the grain boundaries of recrystallized fluorite--are extremely thin and irregular in shape. They lie along curved planes of ellipsoidal shape, between which are zones of clear fluorite that contains no fluid inclusions. The three-dimensional aspect of the ellipsoid is clearly seen by raising or lowering the focal plane of the microscope through the polished plate. These fluid inclusions are along grain surfaces of the granulated and recrystallized (healed) fluorite described above, and the fluids probably were trapped during recrystallization of the fluorite.

The fluids in both types of inclusions consist of three phases--liquid water, liquid carbon dioxide, and gas. The carbon dioxide was identified by warming and cooling the inclusion to temperatures above and below the critical temperature (31.1°C) of carbon dioxide and observing the disappearance and reappearance of the carbon dioxide phase.

The filling temperatures of eight inclusions were determined by heating each sample until the gas bubble disappeared in a homogenized liquid phase and then cooling the sample until the bubble reappeared. The measurements obtained are shown in figure 2. Three of the inclusions studied were among those that surround clear granules of fluorite and the other five were among those along the healed fracture planes. Seven of the inclusions filled at 243°±6°C and the other inclusion filled between 255° and 256°C. The uncertainty in the filling temperature is the result of poor optical properties of the inclusions rather than erratic behavior during the heating experiments. The temperatures given are a reasonable approximation of the temperature that prevailed when the deposits were recrystallized and later fractured. A more accurate estimate of the temperature would have to take into account corrections for the salinity of the fluid and the pressure that prevailed when the fluids were trapped. The data for such corrections are not available, but the corrections, if applied, probably would not significantly affect the conclusions.

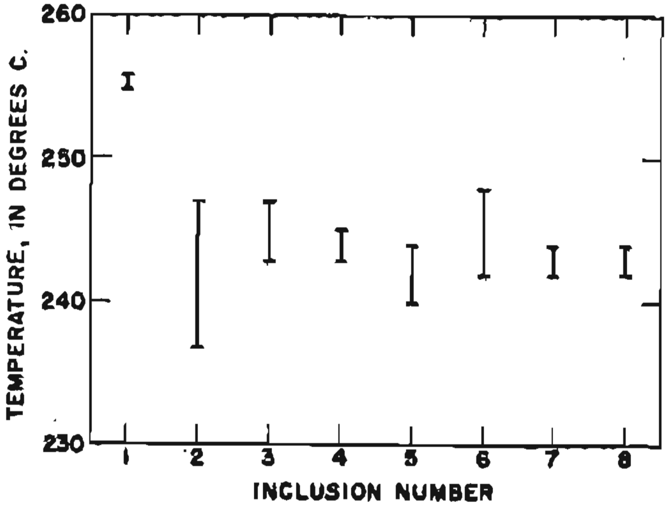

Figure 2.--Filling temperatures of fluid inclusions in fluorite. The fluid inclusions, upon heating, converted to a single phase (liquid) at the temperature shown by the vertical bars. Inclusions 1-3 are along grain boundaries of recrystallized fluorite; inclusions 4-8 are along fracture planes in fluorite.

The composition of the fluid inclusions was determined, in order to estimate the pressure that prevailed and, therefore, the minimum depth of cover in the area when the inclusions were trapped. The carbon dioxide and water were extracted from the fluid inclusions in a sample of fluorite. The fluorite was cut into thin slabs, polished on both sides, and examined microscopically for fluid inclusions showing three phases. The slabs were soaked in hydrochloric acid to remove any traces of calcite from the small veinlets mentioned above. The slabs were then placed in an evacuated chamber in a furnace and heated to 425°C to rupture the inclusions and release the water and carbon dioxide. Experiments showed that calcite, if present, would not release carbon dioxide at this temperature. The released gases were passed into a vacuum line, which is designed specifically to separate carbon dioxide and water, and the amounts of carbon dioxide and water were measured. The fluid recovered consists of 3.2 mole percent carbon dioxide. According to the data of Takenouchi and Kennedy (1964), a mixture of this composition exerts a pressure of 233 bars at 250°C. This pressure is equivalent to that exerted by a column of water about 7,900 feet in height or by a column of rock (density 2.6) about 3,000 feet in height. From these data, the depth of the deposit at the time of recrystallization of the fluorite is estimated to have been at least a few thousand feet.

## Interpretations

The significance of the observations at the Sinuk River barite deposit may be evaluated by synthesizing the events in the geologic history in the area and relating them to the events in the geologic history of the Seward Peninsula.

At the barite deposit, originally layered rocks were metamorphosed (recrystallized and foliated) into a sequence of marble and micaceous schist. These rocks were then deformed: the compositional layers and the micaceous minerals within them were folded and partly fractured, and southerly trending linear structures were developed. Solutions entered the country rocks pervasively and deposited fluorite, barite, sulfide minerals, and some precious metals along the foliation planes and contacts between schist and marble. Some of the introduced material was partly sheared and recrystallized under a pressure equivalent to a cover of a few thousand feet of rock and at a temperature of about 250°C, as indicated by the fluid inclusions in the fluorite. Later, some thin, steeply dipping veins were filled with carbonate and some metal sulfides. These late veins trend west, across the preexisting structures of the metamorphic rocks.

A considerable amount of information on the rocks, geologic structure, and history of the Seward Peninsula has been outlined by Sainsbury, Coleman, and Kachadoorian (1970), and is summarized below. Among the younger, but not the youngest, rocks of Precambrian age is a sequence of marble and schist called the Nome Group, which is exposed in thrust sheets that occupy more than 10,000 square miles of the peninsula. The rocks of the Nome Group have been through two cycles of thrusting, the earlier characterized by intense folding and eastward transport, and the later characterized by imbricate thrusting, without folding, and northward transport. The thrusting was completed before middle Cretaceous time; the thrust sheets have been intruded by granites of middle Cretaceous age (100 million years). Associated with these granites is a regional thermal metamorphism that generated the retrograde metamorphic effects in the blueschist facies so common in the rocks of the Nome Group. In latest Cretaceous, or earliest Tertiary time, about 74 m.y. ago, more bodies of granite intruded the Seward Peninsula. These intrusive rocks have associated ore deposits containing tin, lead, zinc, and fluorite that were introduced into the country rocks in a largely pervasive manner, rather than as vein fillings. Later in Tertiary time, another group of igneous rocks was emplaced. Ores associated with these rocks are fissure-filling deposits containing gold, silver, and antimony. These deposits, notably lacking in fluorite, are the source of some of the gold mined from the famous placer deposits of the Nome district.

The rocks of the barite deposit are mineralogically similar to other rocks of the Nome Group on the Seward Peninsula and they display other characteristics of folding, metamorphism, shear, and even a southward-plunging lineation attributable to northward transport. Because of these similarities, we assign the rocks to the Nome Group.

Continued study of the Seward Peninsula shows that the structure of the Nome region is even more complex than formerly realized. Preliminary geologic maps of the Nome C-1 and Nome D-1 quadrangles (Hummel, 1962a, b), which lie about 10 miles east of the barite deposit (fig. 1), show many faulted areas consisting of markedly different metamorphosed rocks, all designated as Paleozoic in age. In the Nome D-1 quadrangle, the difference between the rocks north and south of the Stewart River suggests that each area could be interpreted as a different thrust sheet whose boundary fault may lie in the valley of the Stewart River. The blue-gray marble and micaceous schists south of the Stewart River have the same characteristics as those rocks at the barite deposit. Thrust sheets involving rocks of the Nome Group probably do extend into the Nome region of the Seward Peninsula.

If the assumption is correctly made that the metamorphic rocks exposed at the barite deposit are part of the Nome Group, then these rocks have been involved in the two cycles of thrusting and the mid-Cretaceous thermal metamorphism. Thus, the folding in the country rocks at the barite deposit probably resulted from the movements in the first cycle of thrusting; and the south-plunging lineations probably resulted from movements in the second cycle. The retrograde metamorphic effects, including the development of some of the sericite and chlorite, resulted from the thermal metamorphism during the emplacement of bodies of mid-Cretaceous granite, some of which pierced the core of the Kigluaik Mountains about 20 miles north of the barite deposit.

The suite of minerals including fluorite, barite, and metal sulfides was introduced to the host rocks by a process of impregnation that seems best correlated with the pervasive mineralization characteristic of that associated with the emplacement of tin-bearing granites, about 74 m.y. ago.

After the introduction of these minerals, they were recrystallized in the presence of carbon dioxide-rich solutions at moderately high temperature (about 250°C). The recrystallization may have occurred late in the original cycle of mineralization or in a later cycle of hydrothermal activity, such as that which produced the later Tertiary fissure veins containing the gold, silver, and antimony in the rocks of other nearby thrust sheets.

The steeply dipping, west-trending fissure veins of calcite and aragonite, with accessory amounts of base and precious metals, were emplaced later than the impregnating fluorite, barite, and sulfide minerals. These vein fillings are not sheared, but the colloform structures are broken and healed, suggesting that the area of emplacement was then under tension, and not compression as it probably was during the time of major fluorite-barite mineralization. These veins are perhaps related to later Tertiary fissure-filling deposits.

The precious metals and antimony are characteristic of the suite of minerals associated with the later Tertiary vein fillings, but not necessarily exclusively so. Gold and silver are detected in areas mineralized by the impregnations associated with the 74-m.y.-old bodies of granite. The presence, however, of seemingly unsheared galena and boulangerite with associated silver and gold, along with fluorite recrystallized at about 250°C at the barite deposit, allows for the possibility that the rocks of the Nome Group in this thrust sheet were mineralized more than once.

## Conclusions

In conclusion, we are suggesting that the area is an attractive target for further exploration for mineral deposits of commercial value.

The complex folding and faulting of several ages in a large area suggests that channels for entry and dispersion of ore-depositing solutions through sheets of foliated rocks probably have been opened during several intervals since Precambrian time.

The occurrence of pervasively disseminated fluorite, barite, and sulfides of lead, zinc, and antimony with associated silver and gold, and anomalous amounts of mercury at the barite deposit suggests that the major mineralization belongs to that associated with the emplacement of the bodies of tin-bearing granite in the Seward Peninsula, about 74 m.y. ago.

The temperature of homogenization of the fluid included in the fluorite--243°±6°C--suggests that sources of hot solutions were nearby, at least once, and that hydrothermal ore deposits displaying the classic features of mineral zonation may occur in the area. The fluorite is partly sheared and recrystallized, events which might have occurred late in the cycle of original deposition or even later. The fluorite certainly was not completely sheared and recrystallized after the entrapment of the fluids. Mineralization might have occurred in more than one cycle of activity.

The vertical and lateral extent of the mineralized rock exposed at the barite deposit is unknown. The structural and lithologic controls of the mineralizing solutions clearly involve the marble exposed in the area. Other marble, which could also be mineralized, may be inferred at depth. Mineralization might have taken place only in the shear zones between the thrust sheets or might have penetrated favorable host rocks in both the overriding and underlying sheets.

Further exploration in this area seems warranted.

## References

Eakin, H. M., 1915, Iron-ore deposits near Nome: U.S. Geol. Survey Bull. 622-I, p. 361-365.

Herreid, Gordon, 1966, Preliminary geology and geochemistry of the Sinuk River area, Seward Peninsula, Alaska: Alaska Div. Mines and Minerals Geol. Rept. 24, 19 p.

Hummel, C. H., 1962a, Preliminary geologic map of the Nome C-1 quadrangle, Seward Peninsula, Alaska: U.S. Geol. Survey Mineral Inv. Field Studies Map MF-247.

______1962b, Preliminary geologic map of the Nome D-1 quadrangle, Seward Peninsula, Alaska: U.S. Geol. Survey Mineral Inv. Field Studies Map MF-248.

Moffit, F. H., 1913, Geology of the Nome and Grand Central quadrangles, Alaska: U.S. Geol. Survey Bull. 533, 140 p.

Mulligan, J. J., 1965, Examination of the Sinuk iron deposits, Seward Peninsula, Alaska, with a section by H. D. Hess: U.S. Bur. Mines open-file report, 34 p.

Sainsbury, C. L., Coleman, R. G., and Kachadoorian, Reuben, 1970, Blueschist and related greenschist facies rocks of the Seward Peninsula, Alaska, *in* Geological Survey Research 1970: U.S. Geol. Survey Prof. Paper 700-B, p. B33-B42.

Smith, P. S., 1910, Geology and mineral resources of the Solomon and Casadepaga quadrangles, Seward Peninsula, Alaska: U.S. Geol. Survey Bull. 433, 234 p.

Takenouchi, Sukune, and Kennedy, G. C., 1964, The binary system $H_2O$-$CO_2$ at high temperatures and pressures: Am. Jour. Sci., v. 262, no. 9, p. 1055-1074.